Maritime Hydrogen Applications in Germany

A study for the German Maritime Centre

(DMZ – Deutsches Maritimes Zentrum)

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EXECUTIVE SUMMARY

Background and motivation

On behalf of the German Maritime Center (DMZ)[1], this study examines the possible and future role of green hydrogen and its derivatives (e. g. methanol, ammonia) in the maritime sub-sectors of shipping, ports, shipbuilding and suppliers, and marine technology. In addition to potential renewable fuel demands, synergies with among sectors will be identified and recommendations derived.

There is a need for a common understanding of the possible solutions, the potential hydrogen requirements and the relevant applications within the maritime sub-sectors.

The maritime sector - like society as a whole - is under pressure to develop and demonstrate concepts and strategies for decarbonization. In particular, renewable hydrogen applications (and those of its derivatives) offer a promising path to successful emission reduction.

Based on robust estimates of possible technology developments, specific development scenarios up to the year 2045, expert interviews and literature evaluations, this study creates an initial basis for further strategy, concept and implementation planning for the maritime industry.

Approach and structure of this study

The study highlights prospects for the short- (by 2025), medium- (by 2030), and long-term (by 2045) application of renewable hydrogen (and its derivatives). Basically, different renewable fuels generated from green electricity (e-) are considered:

- Compressed hydrogen (e-CGH_2) with 35-70 MPa
- Liquid hydrogen (e-LH_2)
- Methanol (e-MeOH)
- Ammonia (e-NH_3)
- Liquefied natural gas (e-LNG)
- Diesel (e-Diesel)

Through all chapters this study is structured in such a way that it is possible to differentiate between the various sub-sectors at any time.

Chapters on shipping cover both inland navigation and ocean shipping, but not fishing and military shipping. Statistics from the Federal Maritime and Hydrographic Agency (BSH)[2] and the Federal Waterways and Shipping Administration (WSV)[3] serve as the main data basis.

The German merchant fleet operates internationally and does not exclusively bunker in Germany. Therefore, this study does not only determine the demand for hydrogen in Germany (which is also generated by international shipowners), but also considers and discusses the future international demand generated by German shipowners.

1 www.dmz-maritim.de, last visited 14.07.2023.
2 www.bsh.de, last visited 14.07.2023.
3 www.gdws.wsv.bund.de, last visited 14.07.2023.

Chapters on ports include both inland and seaports. The study includes the terminals, as well as the surrounding infrastructure, but no local industry.

Chapters on shipbuilding and its supply industry consider in principle all types of shipyards in Germany, the supply industry is considered without service providers ("Dienstleister") and essentially covers the companies from steel production, metal prcocessing and mechanical engineering.

The chapters on marine technology consider a very heterogeneous consumption structure and, due to the (still relatively) small offshore industry in Germany, mainly cover small-scale applications and subsea technology. Aquaculture and fishing are also excluded here.

In order to identify and finally quantify potential hydrogen applications, the first step was to:

Analyzes the energy-consuming processes for all subsectors in **chapter 1** and whether and how hydrogen solutions can cover them.

In **chapter 2**, the technical maturity of each sector was classified (Technology Readiness Level - TRL) and a perspective of feasibility was developed.

In **chapter 3**, methods for extrapolation and specific scenarios for hydrogen applications in the maritime subsectors were developed using the most robust data basis and the technical assessments.

Finally, **chapter 4** extrapolates the potential hydrogen demand and derivatives for each sub-sector and provides an initial assessment against context of the results.

Chapter 5 summarizes the results and key findings and derives conclusions and recommendations for the respective maritime sub-sectors.

Summary of key findings and recommendations

For the overall maritime industry, an annual demand of more than > 119 TWh (> 3.5 million tons) of hydrogen or derivatives is expected in the long term (see Figure 1 and Table 1). According to the current distribution of energy demand, shipping - and international ocean shipping in particular - dominates with about 95 % share. International ocean shipping alone reaches about 114 TWh (3.4 million tons) per year. Most of this demand is expected to occur in the long term. Additionally, it must be taken into account that this demand is generated by the merchant fleet worldwide. Estimates by the "Nationaler Wasserstoffrat" (NWR) were significantly lower for the shipping sub-sector at up to 0.08 million tons (by 2030) and about 0.25 million tons per year in the long term (2040-2050), but did not consider the complete German merchant fleet, only the projected demand from German ships in German ports.

Inland and coastal shipping generates a demand of between 1 - 3.8 TWh (30,000 to 115,000 tons) of hydrogen per year, with the wide range due to uncertainties in the implementation of battery versus hydrogen electric propulsion.

Ports in Germany, if their power supply can be partially met by hydrogen, will have a hydrogen demand of up to 1.3 TWh/a (40,000 tons). If implemented primarily in port handling equipment, the demand will be much lower at about 0.16 TWh (5,000 tons per year).

Shipbuilding and supply industries will generate a demand of between 0.26 - 0.4 TWh (8,000 to 12,000 tons) of hydrogen per year.

In the medium term, until around 2030, the forecasts are subject to major uncertainties. An (pro)active introduction of hydrogen technologies are more likely in the ports and inland navigation sectors. For ocean shipping a major ramp-up is expected after 2030.

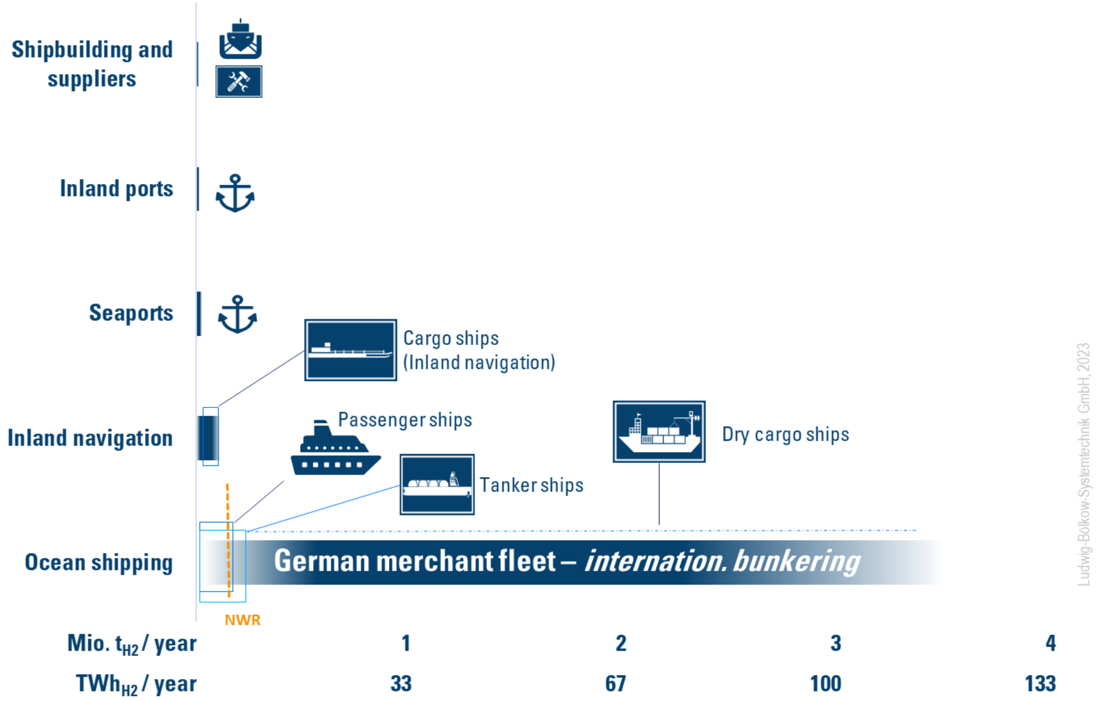

Figure: Summary of potential H_2 demands and derivatives until 2045

Table: Potential H_2 demand throughout the maritime sub-sectors

Sub-sector	H_2 demand in TWh per year	H_2 demand in Mio. tons per year
Ocean shipping	114	3.4
Inland navigation	3.8	0.12
Seaports	0.8	0.03
Inland ports	0.5	0.02
Shipbuilding and suppliers	0.4	0.01
Marine Technology	~0	~0
Overall	**119.5**	**3.58**

The German maritime industry and German merchant fleet can advance the global standard for renewable fuels and global climate protection

The German merchant fleet consists of approximately 1,700 seagoing vessels; mainly container ships, general cargo ships, multipurpose freighters and mineral oil tankers. Due to their long, intercontinental routes, they represent a great potential for the use of renewable fuels and thus for achieving decarbonization of the industry. Dry cargo vessels primarily travel on international routes and therefore require global infrastructure. With a demand of over 100 TWh/a (3 Mio. tons) of hydrogen (or its derivatives), this segment is a key lever for the use of renewable fuels. Internationally navigating tankers have a potential annual demand of about 7.7 TWh (230,000 tons) of hydrogen.

No other application (with the exception of aviation) has a comparably high technical requirement for energy and power density for energy supply as ocean shipping and therefore requires the development of a specific, worldwide infrastructure for international bunkering of renewable fuels.

International developments (i.e., fuel prices / availability) are crucial parameters in the choice of fuels, especially for operators of international routes. Within the maritime sector, ocean shipping has by far the longest perspective or development horizon in terms of introduction and conversion to renewable fuels.

In ocean shipping, the use of H_2 derivatives and combustion engines is favored, especially for cargo ships with long routes, to minimize bunker stops as far as possible. The industry is already testing the so-called "dual fuel engine approach" in a so-called "transition phase" to achieve (local or temporary) emission reductions or to meet local regulatory requirements and to gain experience with alternative fuels. In principle, this approach involves more effort and higher costs compared to conventional fuels. It is nevertheless sensible, as it reduces the risks that will be associated with the technical adaptation, the (global) availability of new fuels and the expected cost developments of these fuels. In the medium to long term, however, a uniform and clear strategy “without further transition solutions” must be found. Shipbuilding and the supply industry can provide a decisive impulse for and contribute to the decarbonization of shipping by developing new technology solutions and new propulsion systems in particular.

The German merchant fleet mainly bunkers internationally. If it were to switch to a uniform renewable fuel and German industry were to offer technology solutions for this purpose, this could also promote the development of an international standard and the establishment of a global infrastructure - especially in the context of international committee and regulatory work.

For large cargo ships with long routes, such as container ships, and trained personnel, the following renewable fuels are particularly favored: methanol (MeOH), liquid hydrogen (LH_2) and also ammonia (NH_3).

A coordination of the German stakeholders on a common fuel strategy is an important and central step for the introduction of a renewable fuel. For this purpose, a common position of Germany for a fuel strategy for international seagoing vessels should be found in close coordination with the political community (the federal states and the federal government). On the European level, a European strategy and roadmap should be jointly elaborated and developed in exchange with the European neighbors, which in a next step can be introduced in international bodies by all European representatives.

Here, the German Maritime Centre (DMZ) could take on a coordinating role and consolidate and advance the process, for example via a coordination platform with industry, shipping companies, ports, science and politics, among others.

German and European cruise shipping and ferries can specifically support and strengthen H_2 infrastructure development in Europe

Cruise ships, with many passengers and tourist routes, as well as ferries are under increasing public pressure for sustainability adaptations. Due to the transport of passengers, they are subject to very high safety-related certification requirements. This is particularly relevant for the choice of renewable fuels. For example, the use of ammonia (NH_3) is practically ruled out here due to the hazard class. The use of methanol (MeOH) also has an increased hazard potential for humans compared to conventional fuel.

For today's 17 German cruise ships, a potential of approx. 3.3 TWh (100,000 tons) of hydrogen per year is estimated in the long term. For the additional 80 passenger ships over 4.3 TWh/a (130,000 tons). For the nearly 1,300 ferries and passenger ships, most of which operate internationally, some only nationally, consumption is assumed to be just under 0.1 TWh (30,000 metric tons) per year.

For routes along the coasts, e. g. in (Northern) Europe, synergies with road traffic could be exploited or developed especially in the context of compressed hydrogen (CGH_2) applications.

Today's main and auxiliary systems with combustion engines could be replaced in the future on cruise ships by modular and scalable fuel cells (FC) supplied with hydrogen.

The conversion of passenger ships along the coasts to fuel cell systems should be advanced in a targeted manner. The use of synergies in the development of logistics for hydrogen along the coasts of Europe (e. g. with road transport, gas networks and industrial sites) opens up availabilities of further bunker options. Together with the shipping companies, the shipyards and politics (federal state, federal government, EU), a uniform approach and a time schedule should be developed for this purpose.

In such a strategy, the role (as a "first mover") and the opportunities for cruise shipping in and for Europe should be worked out. Synergies with national / European infrastructure planning and H_2 strategies should be identified, including the European H_2 strategy and the role of European shipping, as well as the development of a hydrogen infrastructure in Europe.

It is recommended that industry, ports, the (northern German) states, the federal government, and European neighbors jointly develop a strategy that leads to a supply strategy "green H_2 from offshore plants".

This could be done, for example, under the coordination and leadership of the German Maritime Centre, which can bring together both maritime stakeholders and political representatives for coordination and joint development of strategies and goals.

With the development of concrete timelines until 2030 and for 2030 to 2045, possible contributions from offshore plants in the North Sea and the Baltic Sea should also be specifically included in the planning. Based on this, H_2 quantities and contributions for the European Hydrogen Backbone[4] and the German hydrogen network[5] can be derived and planned for.

The seaports in Germany and Europe can become energy hubs and thus central locations for the bunkering and distribution of renewable fuels.

Inland vessels are subject to local emission regulations and are an important part of regional energy concepts and H_2 infrastructure planning.

4 https://ehb.eu/, last visited 19.07.2023.
5 https://www.bmwk.de/Redaktion/DE/Pressemitteilungen/2023/07/20230712-planungsstand-deutschlandweites-wasserstoff-kernetzes-fuer-kuenftige-wasserstoff-infrastruktur.html, last visited 19.07.2023.

In addition to electrification with battery systems, a relevant part of the inland vessels (mainly freight motor ships, but also ferries and larger passenger ships, especially with higher power requirements) will have to be converted to green hydrogen / derivatives in order to achieve the decarbonization targets. Overall, a long-term demand of just under 2.8 TWh/a (85,000 tons) of hydrogen is estimated for the nearly 2,900 cargo ships, bunker boats, push boats, and pusher tugs. For passenger ships, including ferries and passenger ships, there is a potential for the use of just under 0.1 TWh (30,000 tons) of green hydrogen annually.

For the use of fuel cells in inland navigation the development and market launch of fuel cells for stationary combined heat and power plants (CHP), trucks, buses and trains offer synergies. A broad market launch of a new fuel cell technology platform for commercial vehicles is planned for 2026. Fuel cells offer a scalable option for zero-emission propulsion for commercial passenger and cargo inland waterways using various alternative fuels.

The long service life of inland vessels requires early introduction of durable robust fuel and propulsion options (otherwise there is risk of structural failure).

Beside the use of methanol (MeOH), hydrogen in particular is considered as an option for inland vessels. The advantage: Hydrogen opens up synergies in the development of an H_2 infrastructure (especially compressed hydrogen - CGH_2). However, the low H_2 storage density (volumetric) requires an adapted bunker logistics strategy. For an optimized integration of CGH_2 tanks in inland vessels, a new construction as "Future-Fuel-Ready" (innovative concepts) is mostly preferred over a retrofit (integration into existing vessel design, optimized for diesel and combustion engine).

For a specific development of a decarbonization strategy for German inland navigation, the conversion to fuel cell propulsion systems and the use of hydrogen should therefore be examined and investigated, for example as part of a specific feasibility study in close involvement with the maritime industry, shipping companies and ports. This should identify and consider the synergies of logistics and infrastructure planning for CGH_2 in coordination with the development of H_2 infrastructure in road transport, regional H_2 strategies, and especially ports. It is recommended to develop specific bunkering infrastructures for inland vessels with pressurized hydrogen, e. g. in the context of a nationwide study as well as in the context of regional H_2 concepts. For this purpose, inland lakes, rivers and the coastal region should also be specifically included and examined in the further planning and development of the infrastructure of pressurized hydrogen refueling stations.

Most inland vessels will probably not be replaced by new vessels (e. g., with new design), but will have to be retrofitted due to the long period of use. For these vessels, robust bunkering strategies or refueling facilities should be adapted and provided at the rivers (especially at the river Rhine), lakes (e. g. Müritz, Lake Constance) and coastal regions.

Ports - pillars and energy hubs of the energy transition

Ports are attractive places to build new infrastructures for green H_2 and its derivatives. As so-called "green energy hubs" ports can advance the energy transition in Germany and internationally, as well as be a driver for the further development and conversion of the energy infrastructure. In many ports, studies, demonstration and pilot projects and planning are already underway. A national port strategy[6] is currently being developed, which can form the basis for further details from 2024 onwards.

Ports are transshipment points for goods and commodities, logistics locations with links to road and rail transport as well as inland waterways. Renewable fuels could be imported to Germany here and could also be bunkered for seagoing and inland vessels.

In the port itself, handling equipment currently requires the most fuel and will consume up to 0.2 TWh/a (5,000 tons) of hydrogen in the long term. Further energy requirements arise from real estate for power and heat supply, for which ports typically also operate local natural gas-supplied CHP units. The increasing demand for electricity (including shore-side electricity, container cooling capacity, etc.) poses challenges for ports, which must optimize their energy supply and switch to low-emission fuels. If hydrogen solutions are also implemented in this area (for example, to mitigate peak load), a total of up to 0.8 TWh/a (25,000 tons) of hydrogen may be required in the seaports and a demand of approx. 0.5 TWh/a (16,000 tons) in the inland ports.

Hydrogen (or its derivatives) also opens up opportunities for new or expanded business areas. For example, the locations for the import of hydrogen / derivatives are not yet available or defined. Also, storage and distribution (e. g. on German waterways) and at import locations (ports) are not planned yet. Ports have an opportunity to move from energy consumers to energy service providers. Bunkering of renewable fuels also holds potential for them, especially with respect to a potentially increasing demand in (Northern) Europe in case of a conversion of shipping (especially passenger ships and ferries) to pressurized hydrogen.

It is recommended to specifically advance the development of holistic concepts for the transformation of ports into "energy hubs of the energy transition" (e. g. in individual federal states and their locations or in a broader perspective in a federal government study). In addition to the import of energy, in particular the synergy in the conversion of handling equipment, the connection of logistics (rail, road, inland waterways), local / regional electricity and heat generation and the possible role of the ports in securing the energy supply (including grid stability through fuel cell plants) should be worked out.

Shipbuilding and supply industry can use their "know-how" to secure technological leadership worldwide

In shipbuilding, hydrogen, as well as H_2 derivatives, open up opportunities for the substitution of fossil fuels for handling equipment and in logistics. In addition, hydrogen will continue to be used in existing applications (e. g. hydride storage manufacturing). Greater potential is offered by natural gas substitution with green hydrogen, e. g., in shipyards for stationary power generation in cogeneration units (FC or turbine). In the medium to long term, the implementation of combined power and heat generation with hydrogen offers synergy potential, especially for shipyards with large heat requirements (large halls).

Suppliers will use hydrogen actively and already in the medium term. In the long term, shipbuilding and suppliers are expected to require a total of about 0.3 TWh (10,000 tons) of H_2 per year - about 0.1 TWh/a (4,000 tons) of this by the shipbuilding companies themselves. Even if H_2 does not play a major role for decarbonization strategies in the shipbuilding and supply industry, the transformation of the maritime

6 https://bmdv.bund.de/SharedDocs/DE/Video/Youtube/einspielfilm-hafenstrategie.html, last visited 18.07.2023.

industry will only be possible with the know-how on propulsion, power generation and auxiliary systems. In addition to the new construction and re-design of ships for an optimal design and integration of renewable propulsion systems, numerous existing ships will have to be converted in the coming years and decades.

Marine technology provides offshore technology for green fuel production: Large quantities of hydrogen can increasingly be produced directly at sea, requiring regular maintenance to ensure a safe and reliable infrastructure

In marine technology, potentials for hydrogen-based energy supply for decentralized and modular power supply of small applications (e. g. obstruction lights, autonomous measuring and control devices, communication systems) have been identified. Since the focus of research does not always put economic efficiency in the foreground, no relevant "mass market" is to be expected beyond individual applications. Thus, no significant hydrogen demand can be assumed in the short to medium term. Even in the long term, the consumption of hydrogen directly at sea is rather unlikely, even though possible PtX plants[7] are being discussed. In any case, the greatest role will be played by the offshore production of hydrogen, which will at the same time create potential for maintenance technology as well as monitoring, control and safety technology.

Maritime sector influences and enables the energy transition

- Today as in the future - maritime transport is an important and central lever of the supply of goods to Germany (today about 90% of goods are transported by sea).
- For the switch to renewable energies, energy imports will also increasingly take place via sea routes, renewable energies will be provided from offshore plants and thus northern Germany will play an increasingly important role in the energy transition.
- Ocean shipping needs and offers an international solution for successful decarbonization. The German maritime sector can also use the great leverage of its merchant fleet to lead the way worldwide, seek alliances and set international standards.
- On the coast of Germany and especially in Northern Europe, synergies should be used specifically for the development of a hydrogen infrastructure and logistics in road transport and also the gas infrastructure. Passenger ships and ferries in particular offer potential for the expansion of a pressurized hydrogen infrastructure in the North and the Baltic Sea.
- Seaports can and should be rapidly converted and positioned as energy hubs for renewable fuels. Together with inland ports, they can drive the regional development of green hydrogen use and supply. In addition to transshipment equipment, logistics areas (shunting and trucks) are the main areas of application for the conversion to hydrogen.
- Inland navigation can benefit from technology developments in fuel cells for trucks and also from the development of the hydrogen infrastructure.

[7] PtX – Power to X, with X as variable for the generation of H2 / derivatives from renewable electricity.

- The decarbonization of shipping through hydrogen and its derivatives holds a high potential for creating and expanding the value chain in Germany. A reorientation and specialization of the shipyards and supplier industry can be achieved by focusing on fuel cell propulsion systems with hydrogen concepts and methanol for inland waterway vessels, ferries and passenger ships. In coordination with industry, ship operators, ports and politics, specific products are to be positioned on the market in a targeted manner and at an early stage, and the German shipbuilding industry is to take on a pioneering role, gain experience in projects and thus benefit from the expected ramp-up of renewable drives in the early 30s.
- Marine technologies can make valuable contributions to the expansion of offshore production of green fuels. Large quantities of hydrogen can be produced directly at sea. This requires infrastructure to be built and maintained (above and below the sea surface). The construction and maintenance of energy production facilities in the North and Baltic Sea (including offshore facilities, artificial islands, pipelines) offer new areas of application for marine technology. This is important to further advance research and implement the requirements for safety, monitoring and control of facilities (including autonomous systems, vehicles and even plants). The development of a coordinated strategy of marine technology providers and developers of (offshore) hydrogen infrastructure is recommended, e. g. with the DMZ as an anchor point between offshore developers and other sectors.

All these processes require continuous coordination and moderation

It is recommended that the German Maritime Centre (DMZ) continues and coordinates the further exchange within the sub-sectors, as well as across the entire maritime sector, with industry, shipping companies, ports, science, associations and political institutions (federal states, federal government and Europe). A coordination platform could provide the appropriate framework and also support the exchange between the maritime sub-sectors with the other sectors and actors of the energy transition. The German maritime sector can influence and create the framework and conditions that enable the energy transition like hardly any other sector - not only in and for Germany but internationally.

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